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CONSIDERATIONS FOR ECM TESTING AT DREO

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ABSTRACT

This note addresses the basic issues involved in modelling simulations in DREO's Electronic Warfare Engagement Simulation Facility. Fundamental design and implementation problems in DREO's attempt to model missile attacks against simulated targets are highlighted and possible solutions are presented. This note also examines some of the advantages and disadvantages of open–loop versus closed–loop hardware testing at DREO. Alternative simulation approaches using solely software models or a Modular Adaptable Radar Simulator facility are discussed.

RESUME

Ce rapport présente les différentes facettes impliquées dans l'élaboration de modèles de simulation en guerre électronique utilisé dans les installations du Simulateur d'Engagement de Guerre Electronique au CRDO. Les problemes fondamentaux auxquels le CRDO a du faire face dans l'élaboration d'un modèle d'attaque de missile contre une cible simulé ont été soulignés et les correctifs possibles y sont présentés. Ce rapport examine aussi les avantages et désavantages entre les vérifications de quincaillerie en circuit ouvert ou fermé, effectués au CRDO. On y discute aussi de solutions alternatives comme l'utilisation de modèles simulés uniquement par logiciel ou d'une installation comme le MARS (Modular Adaptable Radar Simulator).

EXECUTIVE SUMMARY

The Electronic Warfare Engagement Simulation Facility (EWESF) at the Defence Research Establishment Ottawa (DREO) was designed and built to test radar jammers and techniques. The goal of the EWESF is to simulate the electronic environment of a radar guided missile attack against a target carrying electronic countermeasures. The simulated missile should process radar data and fly a realistic trajectory to the target. The effectiveness of countermeasures can be determined by examining the threat missile performance with and without jamming. Based on the original design objectives, the EWESF should be a useful tool in the development of countermeasures for Canadian operational radar jamming equipment.

The EWESF is presently the only Canadian facility available for replicating the electronic environment for countermeasures testing and its status affects Canadian in-country capability to test operational jamming techniques for the RAMSES, ULQ-6, and ALQ-126B jammers. The status and capability of the facility are important for planning the Electronic Warfare Operational Support Centre (EWOSC) and the RAMSES Integrated Support Station (RISS) projects.

This report describes the basic simulator design and outlines some fundamental technical limitations which prevent the facility from simulating realistic closed-loop engagements. The facility presently only has the capability to perform open-loop tests and is not suitable for optimizing operational jammer techniques. Target angular motion is discontinuous, the missile's field of view is too limited, computer speed is too slow to permit real time processing for the missile dynamics model and the missile model itself may not be sufficiently detailed to model anti-aircraft missiles. Several modifications to the EWESF are outlined to address some of these problems. It is recommended that the target arrays be modified to make them continuous but limited to one dimension, that the radar/seeker antenna be mounted on a positioning pedestal to enhance the field of view, that the missile model computer be upgraded once the processing speed requirements have been determined and that the missile model software be redesigned to make it run more efficiently. This would give the facility a limited closed-loop capability for anti-ship missiles, at least. However, the facility will still only have the capability to simulate generic threat missile behaviour which will limit its usefulness for developing operational jamming techniques. This requires detailed threat specific hardware such as the ALQ-170.

The merits and drawbacks of open-loop versus closed-loop countermeasures testing and the requirements for each are discussed. Alternative methods for evaluating countermeasures are also presented in this report.

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LIST OF ABBREVIATIONS

AAA	anti-aircraft artillery
AAM	air-to-air missile
AFEWES	Air Force Electronic Warfare Engagement Simulator
AGC	automatic gain control
AM	amplitude modulation
ASM	air-to-surface missile
COSRO	conical scan on receive only
DREO	Defence Research Establishment Ottawa
DREV	Defence Research Establishment Valcartier
ECCM	electronic counter-countermeasures
ECM	electronic countermeasures
ECMES	Electronic Combat Modelling and Evaluation System
EWESF	Electronic Warfare Engagement Simulation Facility
EW	electronic warfare
FOV	field of view
GTRS	generic threat radar simulator
LOS	line of sight
MARS	modular adaptable radar simulator
NRL	Naval Research Laboratory
RAMSES	Reprogrammable Advanced Multimode Shipborne ECM System
RCM	radar countermeasures
RF	radio-frequency
RGPO	range gate pull off
SAM	surface-to-air missile
SLOS	synthetic line of sight
SSM	surface to surface missile
STARS	Shape Technical Adaptable Radar Simulator
STC	Shape Technical Center
TLOS	true line of sight

1.0 INTRODUCTION

1.1 Overview

The objective of this report is to assess the inherent capabilities and limitations of DREO's ECM Test Facility, the Electronic Warfare Engagement Simulation Facility (EWESF). This facility has evolved over a number of years and there are several design features which limit its capability for testing of ECM hardware. Basically, there are two types of testing that can be done with jammer hardware: closed-loop and open-loop. Closed-loop testing requires the simulation of a complete missile engagement, including the target acquisition process, missile seeker and/or radar tracking functions, missile dynamics including its guidance and control systems, target manoeuvres, target signature characteristics and ECM signals. Such tests produce a quantitative measure of success through the calculation of the missile miss distance. Open-loop testing provides a qualitative measure of acquisition denial, breaklocks or induced track errors in the threat radar. Missile dynamics need not be modelled as the missile does not close on the target in response to its seeker information. The advantage of open-loop tests is that they permit a detailed examination of the effects the jammer has on the tracking radar or missile seeker. This is typically the first step in developing an effective ECM technique. Once this process is well understood, then closed-loop tests can be done to determine the ECM's effectiveness against the total weapon system.

There are three basic factors which impede our ability to conduct closed-loop testing in the EWESF: limited field of view, discontinuous target motion and insufficient processing speed to perform real time tests. These are discussed in detail in the report, as are several potential solutions and their relative merits. Also affecting the usefulness of ECM testing are the limitations of the threat radar simulator (TRS) which is an integral part of the EWESF. These have been examined in Ref. [1]. The validity of any threat simulator is always in question because of the many unknowns in the weapon system being modelled, and the tradeoffs necessitated by modelling Eastern equipment with Western hardware. The TRS has the further handicap of having to model a large number of anti-air and anti-ship weapon systems, which incorporate many highly diverse, and often incompatible, tracking and signal processing techniques. Discrepancies between threat and simulator are amplified in closed-loop tests because errors in any of the many subsystems of a total weapon system could cause erroneous miss distance results. Open-loop testing is less demanding, in that detailed modelling of the threat can be limited to the particular subsystems of the radar or missile seeker that are affected by the ECM.

All in all, the prospects for useful closed-loop testing in the EWESF are slim, especially considering the generic nature of the TRS. A significant development effort would be required on several fronts to upgrade the EWESF to the point where it can be used for optimizing operational jammer techniques, which is one of the primary functions of the EW Operational Support Centre. This requirement would probably be better met with a facility such as the General Dynamics Modular Adaptable Radar Simulator. There remains for the EWESF the vital role of open-loop testing, which is as important as closed-loop testing from a research and development point of view.

1.2 Existing EWESF Configuration

The EWESF is designed to simulate the electronic environment of a missile attack against an ECM-carrying target. The present EWESF configuration, shown in Fig. 1, consists of an anechoic chamber which houses a threat radar tracking antenna at one end and an array of dipole antennas for simulating targets at the other. The missile body is assumed to be perpendicular to the target array wall and all target motion is relative to the missile body center line. This mode of simulation is known as true line of sight (TLOS). A manoeuvring target is simulated on the dipole array by radiating the target signal through the appropriate elements in order that the threat radar tracks the simulated target. ECM is applied by combining jamming signals from the target with the true skin return signal and radiating the composite signal through the array. Target information, as measured and processed by the radar, serves as input to a five degree of freedom software missile model executing on a PDP 11/34 for calculating missile trajectories. The overall simulation is controlled by a PDP 11/44 which receives PDP 11/34 missile position data and, from a pre-programmed target profile, computes a new target array position. The PDP 11/44 computes the necessary target simulation parameters: target signal amplitude, target signal delay, and target angular position relative to the tracker. Controlled switching of dipoles on the target array is performed by another PDP 11/34 which is slaved to the PDP 11/44.

1.3 Missile Guidance

In order to understand the requirements for missile modelling, some basic missile guidance terms as shown in Fig.2 are defined.

look angle: angle between the antenna pointing direction and the missile body center line (assumed to be the missile heading).

field of view (FOV): maximum available radar look angle. FOV is restricted by maximum antenna angular movement or maximum angle subtended by a simulated target.

line-of-sight (LOS): the actual physical line, referenced in inertial space, joining the missile antenna to the target. Inertial space reference of the LOS is usually measured by gyroscopic instrumentation or accelerometers mounted on the antenna. These sensors can also measure the rotation rate of the LOS.

proportional navigation (pronav): a missile guidance strategy in which the missile is commanded such that its body rotation rate is proportional to the rotation rate of the LOS:

$$\dot{\phi}_m = \alpha\dot{\phi}_{los}$$

where ϕ_m is the missile body angle, ϕ_{los} is the LOS angle (both angles measured in earth coordinates), and α is the proportional navigation constant. The curvature of the missile trajectory depends upon the navigation constant. If the navigation constant is small, missile corrections are small in early flight but target corrections and increased manoeuvrability are required as the missile approaches the target. If $\alpha \leq 2$, infinite acceleration is required in the terminal flight region. For greater values of α, major trajectory corrections are performed during early flight resulting in reduced terminal phase manoeuvres. If α is too high (i.e. $\alpha > 8$) and if the missile has

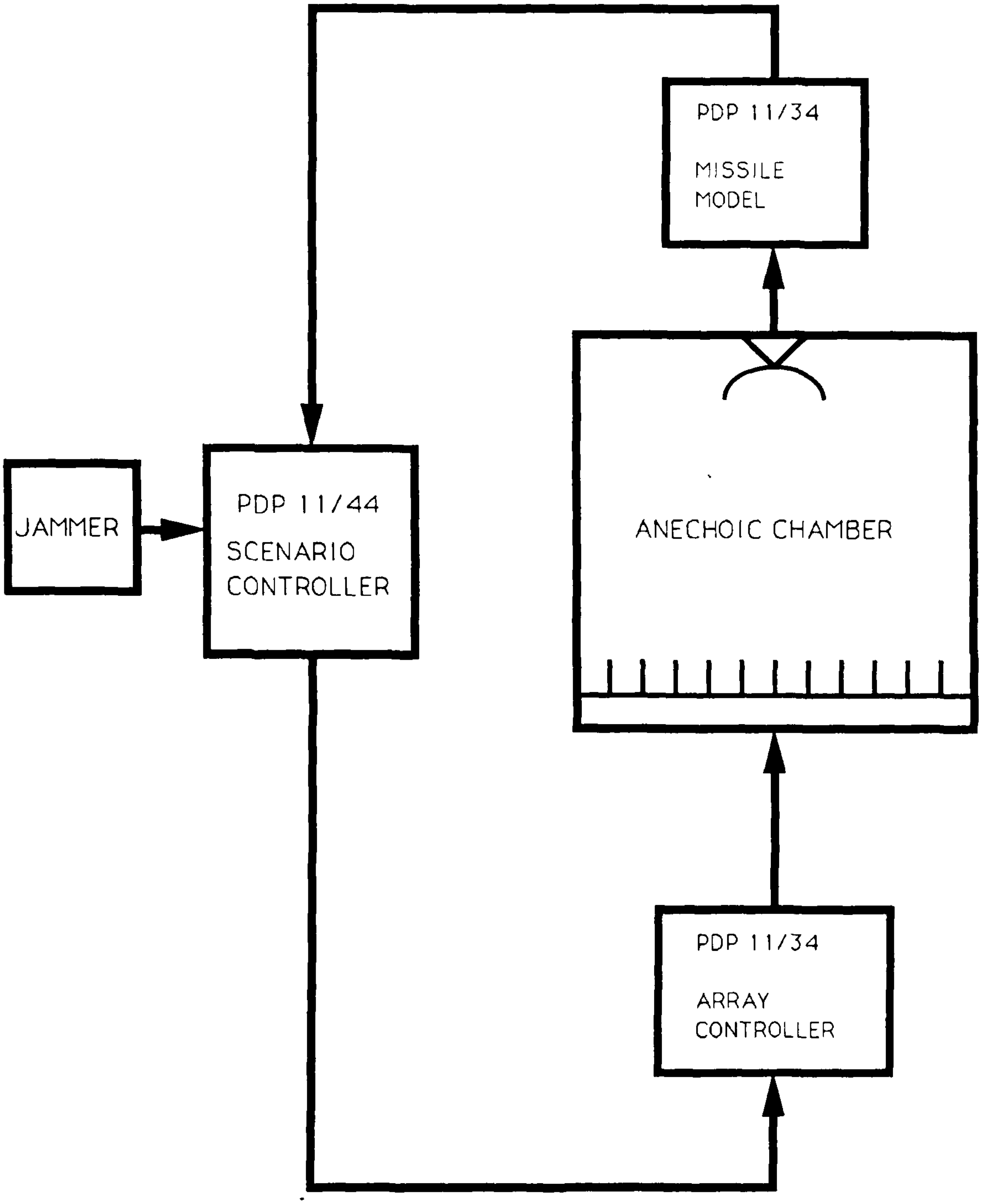

Figure 1 EWESF Functional Block Diagram

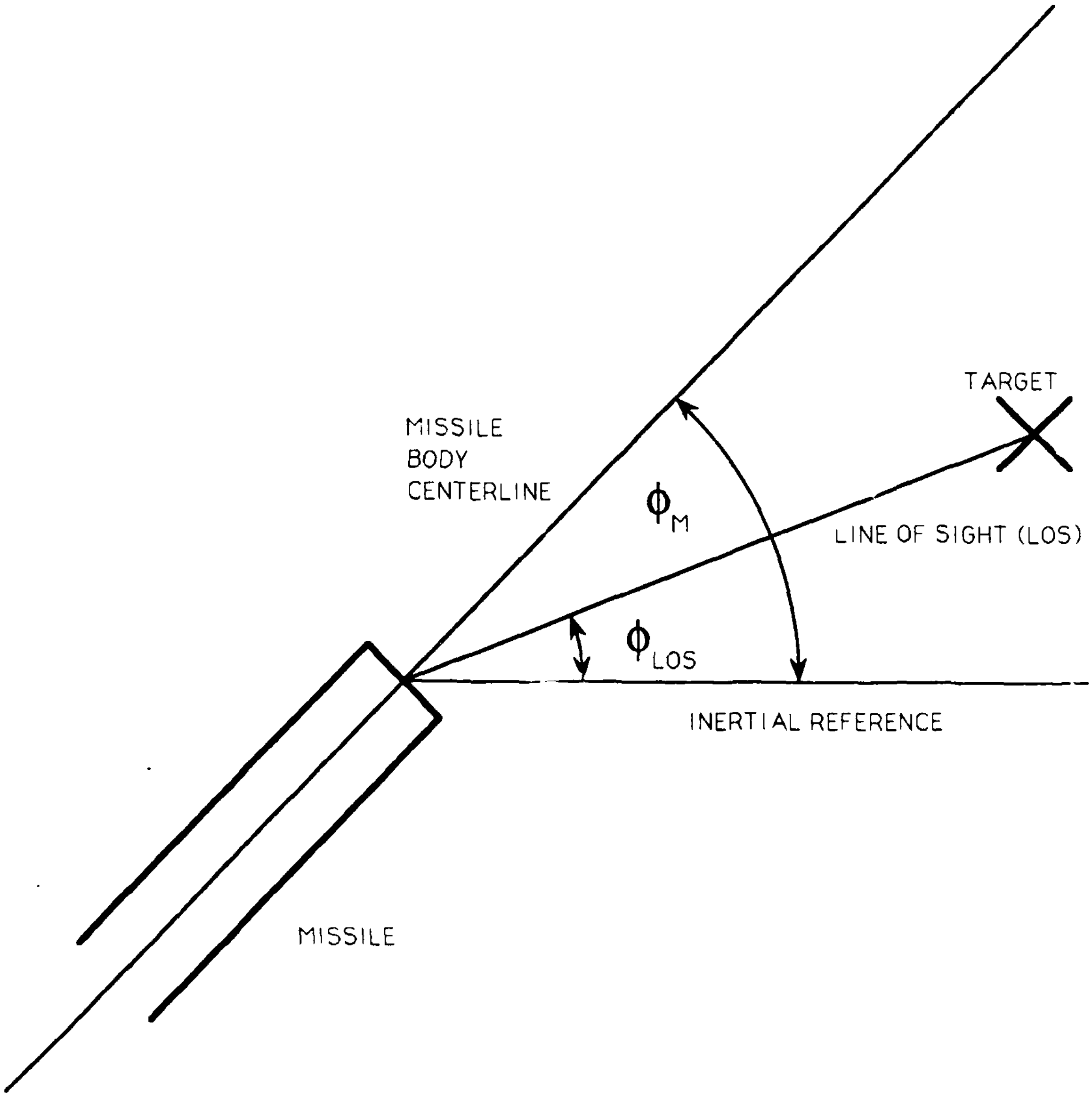

Figure 2 Missile Guidance Frame of Reference

a wide bandwidth response, i.e., is highly manoeuvrable, it will overreact to high frequency noise. Hence the missile over steers and constantly corrects its trajectory, resulting in increased drag. High α is only suitable for well damped low noise systems with a wide bandwidth response. In practice, radar guided missiles use values of α which average in the 3 to 4 range, Ref. [2]. Some missiles vary α during flight depending on velocity and altitude.

pursuit navigation: a missile guidance strategy in which the missile is commanded such that its body centerline lies along the LOS. The missile, in effect, directly pursues the target. This is the special case of pronav where α is one.

1.4 Open-Loop Versus Closed-Loop Testing With the EWESF

Some basic concerns in the modelling of EW simulation platform dynamics for ECM technique evaluation are discussed in this section.

In open-loop EW testing, the missile either flies a pre-programmed trajectory or remains stationary during an entire engagement regardless of the response of the seeker. When countermeasures are applied, effects on the radar such as loss of lock, increased acquisition time, angle errors, and range errors can be observed and analyzed.

Open-loop testing permits detailed analysis of jamming technique effectiveness on a radar. For example, the angle and range tracking errors induced with different radar jamming techniques can be studied. Open-loop testing is a very useful tool for basic development of an ECM technique but does not give a quantitative indication of its effectiveness. The operational protection provided by an ECM technique is unknown unless the resultant missile trajectory is calculated.

In closed-loop testing, the missile trajectory is determined from its radar inputs, guidance laws, autopilot implementation, and aerodynamics. The overall effectiveness of countermeasures is evaluated from the trajectories flown by the missile with miss distances providing a quantitative measure of technique effectiveness. Hence closed-loop testing is required for optimizing operational jammer techniques for specific threats. However, it is equally important that the threat be accurately replicated - without an accurate, validated threat radar simulator and missile model the miss distances can only provide a qualitative measure of relative effectiveness of various techniques. It has long been recognized that Canada cannot afford to build threat specific simulators, hence the development of a <u>generic</u> threat radar simulator. Although the TRS has failed to meet expectations in terms of being sufficiently adaptable to provide a close match to most threats, it has been invaluable for gaining experience in conducting lab tests of jamming equipment. This has been extremely useful for tests at AFEWES, NRL and White Sands Missile Range.

Although closed-loop testing with validated threat replicas is the ideal, there is also merit in conducting open-loop tests with the TRS. There are a number of questions concerning the ALQ-126B for example, that could be answered with open-loop tests. What do the techniques look like to a radar operator? What effect do they have against a monopulse system? Can the operator learn to recognize the jamming and deal with it ? Are there manual adjustments that an operator can make to defeat it? It has been claimed, Ref. [1], that the LOG amplifiers in the TRS are too well matched to represent Soviet systems, yet no effectiveness measurements of the 126B's AM technique have been made with the TRS. It probably is not known just how well matched (or unmatched) the Soviet IF amplifiers are, but it is possible to reduce the effects of channel imbalances by periodically reversing the two channels. By introducing a known amount of channel imbalance in the TRS receiver it could be determined just how effective the channel reversal technique might be as an ECCM. Even with "matched" amplifiers, there is still a dB or so of imbalance which varies with signal level. Varying the jammer output power at a slow rate relative to the AM frequency might enhance effectiveness.

For naval ECM, it seems that the best strategy for on-board jamming is to assist with lock transfer rather than attempting to cause break-lock. The difficulty of pulling the seeker's range gate away from the ship's skin return makes transferring seeker track to a decoy or chaff cloud much more attractive than a momentary break-lock. Reacquisition would probably be fairly quick and there might only be time for 2 or 3 break-locks before the seeker burns through the jamming for a modern supersonic ASM. Studies of the lock transfer process could be done in the EWESF with open-loop tests.

1.5 Missile Model Requirements

An accurate and thorough simulation of a threat missile is necessary for useful closed-loop runs. A realistic missile model contains several basic elements:

seeker: requires some sort of tracker such as the threat radar simulator (TRS) or an operational seeker to measure the apparent target position and apparent target rate relative to the missile.

guidance module: determines the desired missile acceleration necessary to intercept a target based on a navigation strategy.

autopilot: this section generates a control surface setting to produce a desired acceleration.

air frame forces and moment calculation: knowing the position, air speed, missile orientation, and control surface setting, the forces and moments acting on the missile are calculated. Wind forces can be added as a random variable in multiple runs.

trajectory calculation: if the forces and moments acting on a missile body are known, the missile's velocity and position can be calculated by integrating accelerations.

The inputs to a missile simulation are measured seeker parameters such as range, velocity, azimuth, elevation, azimuth rate, and elevation rate. These parameters are derived from measuring both the skin return and jamming. The outputs are missile position (x,y,z coordinates) and orientation (pitch, yaw, roll angles).

If a realistic, threat-specific closed-loop simulation that produces miss distances is required, all these sections must be accurately modelled using detailed intelligence information. Calculating trajectories and obtaining miss distances of real threats requires detailed knowledge of the aerodynamic characteristics of the missile. Important missile system parameters such as aerodynamic coefficients, time constants, gains, and damping constants are frequently not available and must be estimated based on missile design experience, which is lacking in Canada. This limitation makes it difficult to produce accurate simulations.

During the simulation of a missile engagement, the calculations of missile parameters must be constantly updated for each iteration. The update interval should be sufficiently small that the simulation has high fidelity and the calculated missile trajectory is accurate. As a general rule, the total computing time required to perform an iteration which models a process should be less than the smallest elapsed time of that process. Typical simulations have an update interval on the order of 20 msec. If a scenario control computer does not have the capacity to compute missile trajectories in real–time, a computer dedicated solely to performing real–time missile calculations would be required.

Timing is critical for performing real–time, hardware–in–the–loop simulations. If precise hardware/software synchronization is not achieved the simulation can be severely degraded, possibly resulting in significant position calculation errors for supersonic missiles. The dynamic LOS requirements for manoeuvring air targets can be especially large.

2.0 SIMULATOR DESIGN LIMITATIONS

2.1 Field of View

The following discussion is based on the present true line of sight (TLOS) implementation of the missile simulation, wherein it is assumed that the missile body is always aligned perpendicular to the end wall of the chamber.

The radar FOV is limited by the finite size of the anechoic chamber end wall. The dimensions of the EWESF at DREO are 12 ft x 12 ft x 44 ft. The Threat Radar Simulator (TRS) antenna requires a minimum of 40 ft path length in order for the target to be in the far field based on a D^2/λ requirement (where D = antenna diameter, λ = wavelength). With the maximum available length of 44 ft, the FOV is $\pm 7.7°$. Such a FOV presents problems when simulating closed–loop air engagements for missiles which use a pronav guidance strategy. Unlike pursuit guided missiles which respond to LOS angle measurements, pronav missiles respond to the LOS rate. Depending on the missile and target orientation at launch, a missile can have a sufficiently large look angle to the target that it exceeds 7.7°. Some missile seekers have look angles up to 60°. Only if the missile is flying along a direct collision course with a non–manoeuvring target will the look angle remain unchanged. There are few scenarios in which the look angle will be limited to 7.7°. A similar problem arises for simulating anti–ship missile engagements because some missiles incorporate high dive angles in their terminal attack phase which exceed the array's available 7.7° FOV.

The limited size of the anechoic chamber necessitates that simulations confine targets to a narrow angular sector relative to the radar using the TLOS mode. These scenarios are not representative of actual engagements unless the target is at a large range from the radar or the missile is flying an essentially direct trajectory to the target such that the look angle variation is limited. The flexibility of any tests will therefore be limited. A limited FOV simulation would be adequate for the terminal phase of a non–diving anti–ship missile attack or for an anti–air missile chasing a low manoeuvrability target. Limited FOV is a problem with two widely separated targets during the terminal homing phase of a semi–active or active missile. It is also a problem when reacquiring a highly manoeuvrable target following radar breaklock since it is unrealistic for the target to remain approximately along the seeker's boresight axis.

2.2 Target Motion

In the current configuration, problems arise due to discontinuous target motion simulation by the array. The array presently consists of 3 interleaved arrays (1 x 16, 8 x 8, 16 x 16) upon which target motion is simulated by sequentially switching adjacent elements on and off. The number of possible target positions is initially given by the number of antenna elements. These are known as real elements. Additional target positions are generated between elements by feeding two adjacent elements with equal amplitude and phase. These are known as virtual elements. Discrete switching between these available target positions causes the radar to track with a discontinuous motion. This degrades : target data measured by the tracking radar because there are zones on the array ir. which targets are poorly simulated.

Discrete target positioning affects the simulation of command guided missile systems. Command guided missiles require precise angular measurements of target position by the tracking radar for computing missile guidance commands which are uplinked to the missile. At large target ranges, tracking radars for command guided threats must accurately measure angle since angle inaccuracies lead to large errors in absolute target position estimates. The target elements are separated in angle by 0.48° in the array assuming the original array dimensions and element spacing are preserved. The tracker must accurately determine target position in angle to much less than 0.1° for a typical real threat but at a target range of 5 km, the uncertainty in absolute position with the existing array is 40m with a 0.48° angle error. This error could lead to significant errors in the missile guidance calculations. Since the Threat Radar Simulator has angle uncertainties due to tracking noise of ±0.05° in the azimuth plane and ±0.075° in the elevation plane, Ref. [3], which are less than the 0.48° discontinuity errors, the tracking radar movement will be abrupt. The array is thus not suitable for command guidance simulations because of large errors in radar-measured target position.

Discrete target motion also causes problems in the simulation of missiles guided by proportional navigation. The LOS should rotate smoothly and continuously with target and missile manoeuvres during actual engagements. Because of discrete target motion in the current EWESF configuration however, the LOS varies discontinuously resulting in discontinuous radar tracking. Inputs to the missile guidance unit consist of steady LOS values separated by abrupt steps and the resulting missile responses are unrealistic. The missile simulation software can be modified to filter the inputs but this effect would degrade the missile's dynamic response. Conversely, with no data filtering and a high proportional navigation constant, abrupt accelerations will be requested by the autopilot. Implementation of a selective data filtering scheme to distinguish array switching jumps from true target manoeuvres is impractical. Pursuit navigation guided missiles also cannot be realistically simulated because the LOS changes abruptly. Hence the missile heading will be commanded to change abruptly. Therefore, the current array configuration is unsuitable for implementing any realistic missile guidance law.

2.3 Processing Capability

Originally, the PDP 11/44 had the task of computing a new graphics display during each iteration of the scenario. This effect significantly slowed down the simulation so that missile inputs and calculated trajectories became unrealistic. The scenario ran in a simulated "real-time" mode in which the computer's internal clock was checked after each iteration to determine the elapsed computing time. This elapsed time between iterations served as the simulation "update interval". This value was approximately 0.5 s which is clearly inadequate for any dynamic simulation where update intervals on the order of milliseconds are required for realistic missile dynamic responses. This problem could be reduced by transferring the graphics calculations to another processor. As an interim solution, the graphics display has been removed from the simulator altogether.

The software missile model currently runs on a PDP 11/34 which is interfaced to the 11/44. The simulation loop computation interval can be user specified but this value does not correspond to the actual elapsed computing time. The model might update the missile state during every 50 msec of flight while the 11/34 might require 200 msec in actual time to do so. Hence the model does not run in real time where simulation computing time must be synchronized to the actual time elapsed in a modelled process. The PDP 11/34 can be replaced by a PDP 11/84 which would increase the processing speed by a factor of 3.5. This would come very close to satisfying the real time requirement, and streamlining the missile model software might provide an additional reduction in computing time. Actual requirements will have to be determined once the facility is back in operation. It may also be necessary to modify the missile model software for look-angle requirements.

2.4 Missile Dynamics Model

The Roy Ball Associates (RBA) software missile model is a model developed for the EWESF. It simulates a simplified generic missile with five degrees of freedom: x-y-z translation, pitch, and yaw. The missile is assumed to be roll stabilized. The model attempts to simulate the actual operation of a missile by computing trajectories from elementary aerodynamic, thrust, and guidance analyses. Different aerodynamic properties in the subsonic, transonic, and supersonic flow regimes are not represented. Nor are altitude corrections for air density, air pressure, and gravity represented. Naval simulations of sea-skimming missiles and of typical low altitude anti-aircraft engagements are little affected by these limitations, but serious degradation can occur for high altitude air simulations. The aerodynamic modelling is a first order approximation of subsonic flight laws. This representation is limited because aerodynamic data for all missile speeds and altitudes are necessary to accurately predict a missile trajectory. The guidance schemes implemented in the RBA model are not representative of those used by real threat missiles. A pursuit guidance mode is implemented but in the "proportional navigation" mode the azimuth and elevation rates of the target, as measured by the seeker in the missile's frame of reference, are commanded to zero. A true pronav missile model generates the missile and target positions in inertial coordinates and computes the resulting LOS orientation and LOS rates for input to the autopilot, which drives the LOS rates to zero. The control surfaces, when the missile is viewed in cross section, are assumed to be in a "+" configuration which is representative of only a few threats. Most threat missiles have surfaces oriented in an "X" configuration. This provides a greater possible lateral acceleration using four control surfaces for executing a pitch or yaw manoeuvre. Some threat missiles have airplane-like configurations in which the missile obtains its lift from a body wing. The RBA missile model can not be used to simulate any specific threat missile but it can serve as a useful generic model for generic simulations if some modifications are performed. The aerodynamic modelling can be made more detailed and a proper pronav guidance scheme can be implemented.

3.0 POSSIBLE SOLUTIONS

3.1 Introduction

The problems discussed limit the type of simulations which can be presently performed in the EWESF. The facility is unable to test countermeasures in the detailed closed-loop manner for which it was originally designed. Although limited FOV and the discrete nature of the array limit the facility's usage in simulations, some limited tests might still be possible with the existing facility. The frequency response of the antenna servos may be reduced to smooth out the antenna motion as it tracks a switched target on the array. The abrupt target motion effect would be reduced and testing, though limited, could consist of analyzing jamming effects as the radar tracks a moving target. The results, however, would not be quantitatively meaningful for assessing ECM effectiveness. If no modifications are performed on the existing EWESF configuration, only limited tests are possible. If the TRS is locked onto a single target, basic techniques such as RGPO, AM, and noise jamming can be tested. The missile attack, if modelled at all, is limited to straight flyouts against a non-manoeuvring target in order to confine the simulation to a single dipole. Consequently, the capability to thoroughly test operational jammers such as the ALQ-126B and RAMSES in closed-loop against a detailed simulated threat does not presently exist.

Some of the problems addressed can be corrected through design changes in the EWESF. The following discussion presents some design changes which can be performed to implement continuous target motion and overcome FOV limitations.

3.2 Continuous Motion Array

If relative target motion is realistically implemented on the array, the LOS and LOS rate measured by the seeker will be representative of those of an actual engagement. An electronically controlled array can be rapidly switched so that engagements requiring high LOS dynamics, such as air attacks, are realistically modelled.

Smooth continuous target motion in the anechoic chamber can be simulated from one true element to another by smoothly adjusting the relative amplitudes fed in phase to adjacent elements. To implement continuous motion across the array, significant modification to the existing array is required. Precise attenuator and phase control are necessary since any phase difference biases the tracking towards one element. Figure 3 (from Ref.[4]) shows the tracking point of a monopulse radar as the relative amplitudes and phases of two elements are varied. A phase deviation of 0° is necessary to ensure that the tracking point is in the center of the two sources when their amplitudes are equal. For a given phase shift, the tracking errors are greatest when the two signal levels are approximately equal and decrease as the amplitude ratio increases. For a phase shift of 20°, the tracking error is roughly 0.02° when the amplitude ratio is near 0 dB and the tracking error is roughly 0.01° when the amplitude ratio is greater than 10 dB.

An attenuation of 30 dB is required to bring the radar tracking point to within 4% (0.02°) of the true single source position. Limited attenuation results in a dead zone over which continuous target motion may not be synthesized using two point sources. For example, 30 dB attenuation would result in a dead zone of approximately 8% (0.05°) of the

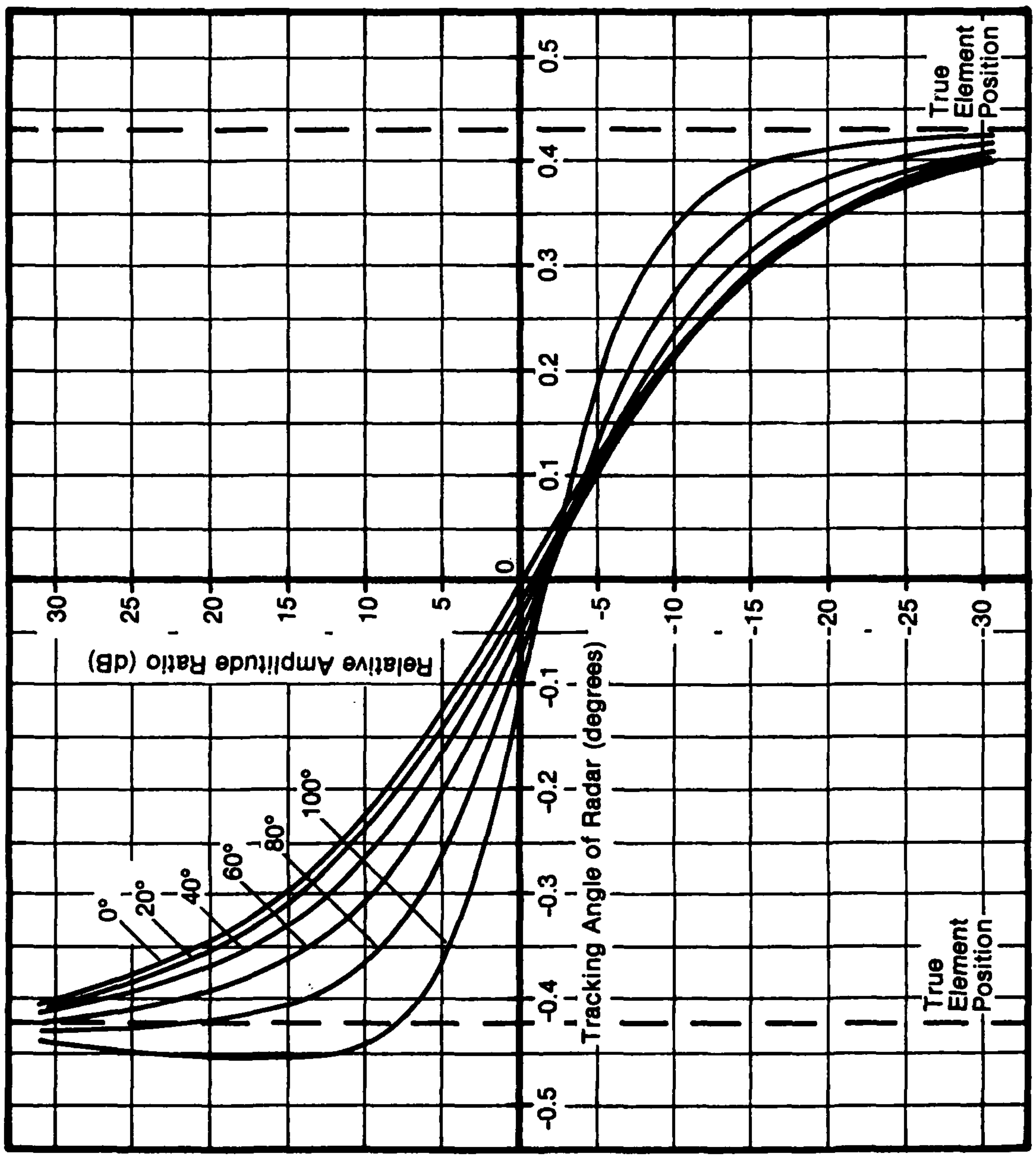

Figure 3 Monopulse Tracking Point of Two Coherent Point Radiators (from [4])

separation between two adjacent elements. Higher amplitude ratios would reduce the dead zone size. In a two dimensional array, four elements must be simultaneously excited to create a virtual target between them. A small zone surrounding each true element cannot be synthesized if the amplitude ratio between the feeds is limited. A target can be simulated in the center of the dead zone by turning on only that element in the dead zone.

Practical implementation can be performed by using commercially available phase compensated digital attenuators which provide small phase shifts with varying attenuations. For example, Triangle Microwave has a unit which provides up to 32 dB attenuation with low phase shifts (i.e. $< 10°$). This device could be used to provide target positioning accuracy to within the tracking resolution of the TRS which would produce continuous radar tracking motion.

Basic operation and maintenance of a continuous target motion array pose several practical problems. The feed structure of the array will be susceptible to temperature variations and mechanical stresses which can alter the phasing provided by waveguide line lengths. The environment must be carefully controlled during a simulation and calibrations should be performed prior to each array usage. To assist with the calibration some type of compensation circuit would be required to monitor both phase and attenuation at the dipole feed points. The feed signals can be conditioned to compensate for any variations in the feed network. Other labs such as NRL, AFWAL and MICOM perform such calibrations - perhaps they could help us set this up. A possible implementation of a continuous array loosely based on the existing array design is discussed in Appendix A.

Control of a continuous array could involve recovering the attenuator and selector switch settings for any desired target position from a look-up table or EPROM. A processor to control each attenuation level for synthesizing a moving target can be used. Frequent updating of the table would be required to account for system variations due to environmental and aging effects.

The design, implementation, and maintenance of a large continuous target motion array is an ambitious task. If RCM decides to pursue this option, the task is best delegated to a contractor with experience in building accurately phased antenna systems. For the short term, the arrays should be limited to one dimension, partly because this greatly simplifies the control of the target position and partly because it limits our investment until we have gained some experience with such a system. Issues such as target positioning accuracy, controllability, dead zone size, temperature effects, and anticipated calibration requirements should be studied.

An alternative to a continuous target motion array is an array that contains sufficient element density that the angular separation of array elements is less than the resolution of the radar. The tracking radar would not detect any discontinuities as it tracks a target across switched elements. For a typical resolution of 0.02°, the element spacing would have to be 0.5 cm, which is much smaller than the physical size of the dipole antennas. Hence this is not a viable option.

Although the discrete target motion problem can be solved, only linear polarization can be achieved with a relatively simple target array. Variable polarization target arrays, such as the unit at AFWAL (Air Force Wright Avionics Laboratory), are required to test cross-polarization jamming in the TLOS mode but they are very complex and costly.

3.3 Mechanical Target Manipulator

Continuous target motion can also be achieved by using a mechanical positioner to manoeuvre a single radiating target in the TLOS mode. This approach would eliminate the requirement for a phase controlled array.

The Contraves Goerz company manufactures mechanical target positioners such as robot arms and x–y positioners. The Model TPS–600 robot arm provides 13 ft of height position range and 8 ft of lateral position range. At a distance of 40 ft, this corresponds to a FOV of ±9.2° in the elevation plane and ±5.7° in the azimuth plane. The maximum arm velocity of 100 in/s provides a maximum angular velocity of 12°/sec. This unit costs approximately $525K (US).

Contraves Goerz also manufactures two x–y target positioners: the Model TPS–200 and Model TPS–202. These positioning units have curvilinear surfaces so that the target sources are constrained to move over spherical surfaces, preserving path lengths while testing infrared and RF seekers. The Model TPS–200 has a spherical radius of 14.25 ft, angular range of ±5°, and a peak angular rate of 1°/sec. The Model TPS–202 has a spherical radius of 16 ft, angular range of ±18.3°, and a peak angular rate of 1.5°/s. These units cost approximately $120K (US). However, their low angular velocities limit their usefulness in dynamic closed–loop simulations and the problem of limited FOV would still be present.

3.4 Positioning Pedestal

Open–loop tests could be easily implemented in the EWESF. The simplest implementation is synthetic line–of–sight (SLOS) which consists of a stationary target and a tracker/seeker mounted on a positioning pedestal. To simulate an engagement, the pedestal moves through the range of relative positions between the missile and target corresponding to a missile attack profile. The radiated target signal is appropriately modulated in amplitude and delayed in time according to range. The motions of the missile and target may be complex but they are pre–set for an engagement and provided that the positioner has sufficient dynamic capability, the angle tracking loops are realistically stressed. In an open–loop simulation, computational speed and complexity are not problems so that the existing PDP 11/44 scenario control computer would be adequate. The pedestal can be programmed to move as the missile progresses through its flight. Positions can be pre–determined as a function of engagement time, calculated off line before simulation and stored in memory. The pedestal can be positioned in real–time using angular position and angular velocity data.

The problems of both limited FOV and non–continuous target motion can be solved in n between the radar and target are implemented by positioning the pedestal. If the antenna maintains track on the target as the pedestal moves, the operation of the antenna drive mechanism and tracking circuits are the same as those in actual engagements, a necessary feature of the simulation for some ECM techniques. The motion is continuous and the FOV is limited only by the range of pedestal motion.

Since both the target and the radar's physical location are fixed in inertial space, the antenna gyros will not detect any LOS movement. The LOS angles must be obtained from the antenna servos which measure angles relative to missile body and the LOS rate can be obtained by differentiating these angles with respect to time. Determining what the LOS angle should be in the first place to drive the positioning pedestal is done in software.

The SLOS mode using a positioning pedestal is one required element for complete hardware tests of the RAMSES jammer in the EWESF. The presence of a RAMSES antenna in the EWESF allows the actual radiation characteristics of RAMSES to be studied and tested. However, other technical issues must be considered for RAMSES testing at DREO.

Mathematical simulations of simple attack scenarios can provide an estimate of engagement parameters such as maximum look angles and maximum angular velocities. Some studies performed by DREV, Ref. [5], analyzed a 1500 m/s missile pursuing a 1000 m/s target. The target's lateral acceleration was limited to 8 g and its longitudinal acceleration was limited to 2 g. The missile's lateral acceleration was unlimited. Three flight paths were studied: a circular path, an S-weave, and a sharp right-angle turn. The maximum angle and angular velocities varied depending upon the type of target profile, the proportional navigation constant, the missile time constant, and the seeker time constant for this simple model. However, for a typical realistic navigation constant of 4, seeker time constant of 0.1 s, and a missile time constant of 0.1 s, the maximum look angle was 34°, maximum angular velocity was 6°/s, and the maximum angular acceleration was $300°/s^2$. Missile behaviour immediately after launch was not considered since, from a countermeasures point of view, the terminal phase is of most interest.

A positioning pedestal could be used in the simulation of ground based trackers and missile seeker radars to overcome the limited FOV problem. If missiles are roll-stabilized, as is the case for skid-to-turn missiles, a two axis pedestal is sufficient. The pedestal could generate elevation and azimuth LOS motion for ground based radars or the pitch and yaw LOS motion for missile radars. Numerous 2-axis position tables are commercially available. The Carco Electronics Model T-920 has an angular positioning capability of ±5 arc seconds and an angular velocity capability of 100°/s, costs approximately $150K (US) and can accommodate payloads up to 100 lbs. The TRS could be mounted on such a unit and could easily achieve a FOV of ±90° in both azimuth and elevation planes. Motion is obtained using electrically driven motors.

The positioning pedestal seems to be best suited to the simulation of missile body motion and to relieving the limited FOV problem, while continuous arrays are best suited to the simulation of target motion and the generation of multiple targets. Pedestals and their control apparatus are a well-developed technology, are purchased as off the shelf units and can easily achieve required positioning accuracies over a wide range of positions. A pedestal is heavy (≈1300 lbs) but it would fit into the anechoic chamber with minor modifications. Reinforcements would be necessary to strengthen the mounting surface. Interfacing to positioning pedestals is performed through an IEEE 488 parallel interface or through a Standard RS232C serial interface. Control can be performed in either the angular positioning mode or the angular velocity mode.

High performance flight tables have better frequency response and are capable of higher angular velocities (typically 500°/s) and accelerations (typically $10000°/s^2$) than the above mentioned positioning pedestals. These units are commercially available from Carco Electronics or Contraves Goerz. They are hydraulically driven to obtain high dynamic performance but they have lower positioning accuracy than electrically driven positioners. Such pedestals are required for simulating closed-loop air engagements with a dynamic LOS. Body motion coupling can also be implemented. Body motion coupling arises from airframe oscillations which affect radar data. Coupling causes radome vibration and apparent variations in the measured LOS even if the true LOS is unchanged. Filtering should remove most of the effects of an oscillating LOS so that, from an ECM point of view, body motion coupling simulation can be neglected. Any technique that works without coupling should be enhanced by body motion coupling since seeker performance may be degraded.

High performance positioners are quite expensive (>$250K US) and would be difficult to fit into the anechoic chamber of the EWESF since they are bulky, exert large forces on their mounts and must be anchored into metallic or concrete supports secured to the ground. Some smaller but lower performance models are appropriate for mounting smaller radar antennas, but they would not be able to accommodate the bulky TRS antenna or an ALQ-170 simulator pod. Appendix B discusses some important features in the implementation of several types of threats.

3.5 Software Flight Motion Simulator With Continuous Target Motion Array

The limited FOV problem can also be solved by implementing a hybrid TLOS/SLOS type of simulation. In this approach, the actual LOS of a scenario is separated into two components. One component is implemented on a continuous motion array in the TLOS mode while the other component is implemented in software in the SLOS mode. The motion and effect of a positioning pedestal is simulated in software. The TLOS component is such that the look angle is always within the target array FOV. For example, if the LOS varies by 35° and the array FOV is limited to 15°, then a maximum of 15° would be displayed on the target array while the remaining 20° is represented in software. In this simulation mode, some criteria must be adopted for separating array-represented motion from software-represented motion. One possible algorithm for dividing the LOS variations is to implement low LOS rates in software and to implement high LOS rates on the array. The boundary separating the two components must be such that all high frequency motion is confined to the array FOV. If the radar hardware only tracks a single component of LOS variations, then the radar angle tracking loops, antenna servos, and monopulse signal processing are not realistically simulated. In theory, however, if the software and hardware are well designed for detailed real-time operation then useful closed-loop tests can be performed.

Implementation of this approach requires real-time computing capability to calculate the missile's position with a detailed missile model and the target position from a combination of software and hardware representations. The LOS orientation and LOS rotation rate are also computed from such a combination and must be accurately determined for threats using pronav guidance. The array also requires accurate target positioning capability. Figure 4 illustrates an implementation of this approach.

A considerable amount of effort is required to properly implement this mode. A continuous array with precise target positioning must be designed and constructed. Real-time hardware and software performance are critical to proper operation in this scheme. Implementing the SLOS mode with a positioning pedestal is a simpler approach and would produce the same simulation results.

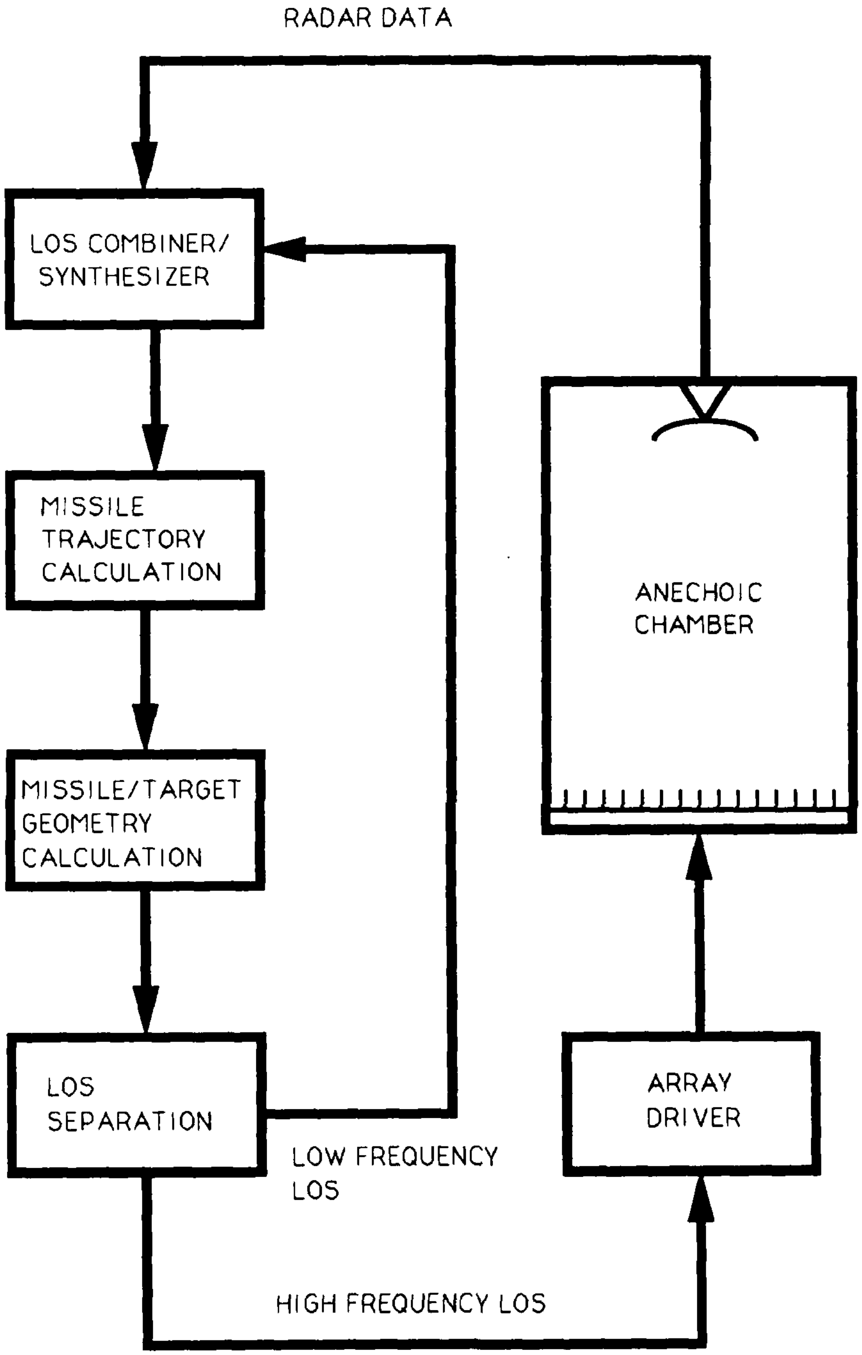

Figure 4 Software Flight Motion Simulator with Continuous Motion Target Array Implementation

4.0 ALTERNATIVE SIMULATION METHODS

4.1 Introduction

The present simulator design is based on a hardware-in-the-loop simulation. Extensive resources are required to modify the EWESF to the point where it is capable of performing realistic closed-loop simulations. Simulations with a generic missile model can be used to evaluate the effect of jamming by observing trends in the trajectories as parameters are varied. Exact miss distance values should not be analyzed in detail but miss distance trends among runs can provide useful information. A significant effort must still be expended in redesigning the facility to perform such generic closed-loop simulations. The existing facility is useful only for performing open-loop testing against a single non-manoeuvring target and the only available radars are the TRS and the MG13. There are alternative simulation methods for studying countermeasures which should be considered.

4.2 MARS Facility

Looking ahead to EW Operational Support Centre (EWOSC) requirements and considering the trends in threat radar development, it will be necessary to have a coherent threat simulation capability. Virtually all anti-air radar guided threats are Pulse Doppler and/or CW and anti-ship missiles are beginning to employ coherent-on-receive techniques. Several options have been considered for obtaining a coherent threat capability, including developing a simulator in Canadian industry, using an AIM-7M missile seeker or an APG-65 AI radar, and buying a Modular Adaptable Radar Simulator (MARS) from General Dynamics. It was concluded that there is insufficient expertise in Canadian Industry to build such a simulator, and that a generic simulator such as MARS would be preferable to a specific Western system which does not adequately model any Soviet system and cannot be modified. A MARS would provide a closed-loop testing capability with both coherent and non-coherent threat types and would be useful for pulse doppler countermeasure research. If there is sufficient operational support to procure a MARS facility, it might be advisable to limit development of the EWESF to improving its open-loop testing capability and adding a limited closed-loop test capability.

The General Dynamics MARS system is used to design and optimize electronic countermeasures techniques against different simulated threats. The system simulates ground based trackers and can simulate several different scan patterns (active conical scan, COSRO, scan with compensation, track-while-scan, and sequential lobing). Parameters such as frequency, pulse repetition frequency, and pulse width are user definable. An operational jammer is interfaced to the MARS and can be tested in real-time, real-frequency, and with real power levels. Simulated threat signals are directly injected into the jammer whose response is combined with a simulated skin return and fed into a threat receiver for processing. Microwave signal levels are controlled by attenuators in an RF head to account for antenna patterns, radar cross section, and scintillation. MARS is marketed to foreign governments as a generic alternative to the threat-specific simulations at AFEWES (Air Force Electronic Warfare Engagement Simulator).

The processed receiver data serves as input to a five degree of freedom missile model which calculates the weapon flyout and miss distance. The simulations are closed-loop and the threats are reconfigurable by reprogramming the receiver hardware and software. A man-in-the-loop feature offers some ECCM capability. One or more missiles may be launched automatically as a function of range or manually by the operator. An anti-aircraft artillery (AAA) software model can be combined with a radar to provide statistical data on the actual projectile pattern around the target. Jamming can also be tested against search or surveillance radars. Moving target indicator, phase shift keying and pulse compression modulation can be implemented.

The MARS system presently suffers from several limitations. The type of tests which can be performed are limited because antennas are not used by the simulator. Jamming techniques such as cross-pol or cross-eye which exploit antenna properties cannot be tested with a MARS. Another important limitation is the lack of glint simulation. Glint can contribute significantly to miss distances and from the point of view of ECM technique development, will enhance technique effectiveness by increasing miss distances. Therefore, techniques can be optimized in a non-glint environment but the miss distances obtained will not be representative of actual values. However, they can serve as useful indicators of relative technique effectiveness.

4.3 Software Modelling

Simulations can also be performed entirely in software. Eliminating any hardware-in-the-loop also eliminates the requirement for real-time computing facilities. The only hardware required is a computer such as a VAX since real-time processing is not necessary. Processing power would still be important to reduce program run time.

Several software simulations already exist to simulate EW engagements. Digital simulations can have a generic approach to modelling threats and engagements while some simulations are based upon specific threats. Generic EW simulations are commercially available from software development companies such as Software Sciences Ltd. and EASAMS Ltd of the UK. Detailed simulations of specific threats appear to only be available through government agencies via international panels such as TTCP or NATO.

Software Sciences has a commercial product, ECMES, which is a pulse to pulse simulation of electronic engagements with countermeasures. Interactions between platforms carrying radars and jammers are modelled. Radars and jammers are characterized by generic models in which the important functional parameters are user-specified. Threat receiver signal processing is simulated at a functional subsystem level. For example, tracking radars are described by parameters such as frequency, PRF, pulse width, amplifier gains, automatic gain control (AGC) properties, and antenna patterns. The radar and jammer are generic models but they can be replaced by detailed models of specific threats. ECMES Phase I does not have closed-loop missile trajectory capability but the missile is flown along a pre-programmed missile-like course. This version is limited for ECM evaluation purposes because missile miss distances are not generated. Phase II will incorporate a closed-loop missile response to its seeker but trajectories will not be accurate because the missile model will be highly simplified. This simulation might still be useful for obtaining estimates of overall electronic warfare systems performance. Simulation accuracy depends on the fidelity of individual radar and jammer models. ECMES has a highly modular design so program modification or customization to specific threats can be readily performed. Phase II, which costs approximately $300K, would be useful for RCM purposes.

Lockheed (Sanders) Canada has an electronic warfare simulation program in which EW engagements are modelled at a system level. The simulation is not a detailed pulse to pulse representation but radars and jammers are functionally modelled at a higher level using less detailed models. The simulation is closed-loop and threat missiles are represented by a six degree of freedom model. Missile trajectories are obtained and miss distances are computed.

These generic system level models are useful tools for assessing overall EW system performance by providing estimates on target survivability with closed-loop simulation. However, simulation accuracy depends on the model's ability to simulate radar and jammer performance. Detailed radar and jammer performance might best be obtained from limited hardware simulations in order to determine the exact behaviour of important subsystems. When the exact behaviour of the hardware is known, these systems can then be confidently modelled in software for integration with the higher level system models. It is the user's responsibility to analyze the intelligence data and customize threat models in order to make the simulation as accurate as possible.

Detailed software models of particular threats can be very useful. For example, NEMESIS is a surface to air simulation developed by EASAMS Ltd for RAE Farnborough. NEMESIS was obtained from the UK under TTCP and different threat models might also be available through these international channels. Development of these models requires detailed knowledge of threat parameters such as receiver processor designs, processing algorithms, time constants, and amplifier gains. Close collaboration with software developers is required using available threat intelligence and best estimates.

The software approach can be very expensive in terms of development costs but it offers the advantage of increased flexibility and minimal hardware cost. It requires a high level of expertise and experience in radar/EW design and detailed intelligence information. Such an extensive capability does not presently exist with Canadian companies to model modern advanced threat systems.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The requirements for ECM technique development and effectiveness assessment include both open-loop and closed-loop testing. Both types of testing have merits. Open-loop testing can be advantageous for detailed studies of the effects of ECM on specific subsystems of the radar; e.g., conditions required for breaklock, acquisition denial, operator confusion, angle or range error generation in the fire control radar or the missile seeker, and lock transfer from the target to a decoy. It is possible to gain a very good appreciation for the effects of the jamming alone with the limited number of variables of open-loop testing. Experimental results obtained in such tests may serve as useful inputs to a closed-loop software simulation. Experience gained in open-loop testing is invaluable for closed-loop tests with foreign simulators.

For optimization of operational jam programs against specific threat weapon systems it is necessary to have a closed-loop test capability. By modelling the missile dynamics and calculating its space state vector together with that of the target throughout an engagement, it is possible to obtain a qualitative measure of success of the ECM in terms of miss distance. The validity of these miss distance results is greatly dependent on the accuracy of the missile model, the detailed modelling of target radar cross section characteristics including amplitude scintillation and angular glint, target range and altitude, target manoeuvres, timing of the missile launch, ECM antenna pattern/blockage, radar operator expertise, and factors such as field of view and non-continuous target motion in the anechoic chamber.

The accuracy of the fire control radar and/or missile seeker model is crucial for both types of testing, but for open-loop tests it is often sufficient to model in detail only the specific subsystem(s) being affected by the ECM. Typically, open-loop testing is done first to gain an appreciation for what ranges of ECM technique parameters are potentially effective. Closed-loop testing can then be confined to a few select jam programs and the numerous other factors of a missile engagement can be added to determine if the ECM is capable of causing the missile to miss its target. Here, the optimization process is normally focussed on the effects on the antenna servo loop and the missile guidance and control system, as errors must build up here if the miss distance is to be sufficiently large.

The short-comings of the EWESF which preclude closed-loop ECM testing have been discussed. These include limited missile field-of-view, non-continuous target motion and lack of real-time computer processing capability. The missile dynamics model may lack sufficient detail and the TRS cannot be made to match the threat in all respects, as would be required for closed-loop tests. Modifications to the EWESF which could give it a limited closed-loop capability include installing a positioning pedestal, adding a continuous motion target array, and increasing the system computing capacity/speed.

5.2 Recommendations

Without any modifications to its existing configuration, the EWESF will be restricted to open-loop tests. There are circumstances which could justify the development of a closed-loop naval engagement test capability in the EWESF. For example, an ALQ-170 pod, which simulates a few specific naval threat missile seekers, may be acquired for the EWOSC in support of RAMSES reprogramming. To incorporate an ALQ-170 into the EWESF, the anechoic chamber with hardware-in-the-loop approach to simulation must be maintained. Continuous target motion for open and closed-loop tests can be obtained by integrating a radar positioning pedestal into the anechoic chamber to provide an interim testing capability. This approach enables closed-loop naval simulations and limited open-loop air tests to be achieved. However, many other RAMSES-specific technical concerns need to be addressed before concluding that testing in the EWESF is practical. The pedestal cost (approx $250K) would represent a reasonable expenditure to provide a continuous positioning capability and a wide field of view. The synthetic line of sight mode can be implemented with a single target dipole on the array. The simulation of off-board countermeasures such as decoys and chaff requires continuous target motion arrays to be implemented to generate multiple targets. These could be limited to one-dimensional arrays to reduce their cost and complexity, without sacrificing too much performance, at least for sea skimming missiles. In addition, the missile model processor must be upgraded so that the calculations can be done in real time. This will require careful timing measurements to be done in order to synchronize the missile dynamics calculations with the system hardware update interval.

The dynamics of anti-aircraft missile engagements are too high for the recommended positioning pedestal. In addition, the TRS has no capability to simulate coherent radars (CW or pulse doppler), while virtually all air threat systems entering service in the past ten years employ coherent radars. For air engagements, then, it is recommended that a facility such as the General Dynamics MARS be procured. This would give us a generic capability for closed-loop testing with both non-coherent and coherent weapon systems. Although designed primarily for surface-to-air weapon systems, it is felt that MARS has the potential for modelling air-to-air and anti-ship weapon systems as well. There is no real alternative to a MARS if Canada is to have an in-country capability for coherent closed-loop testing of airborne ECM techniques. Without it, we would be forced to use US facilities, if and when available, for development and validation of our operational ECM techniques.

6.0 REFERENCES

[1] Wardle, G.A., unpublished report, 1989.

[2] Trottier, G., Arnold III, W.F., Clayton, B.J., Lawrence, R.V., Morin, A., Nugent, J., and Provine, J., TTCP Subgroup W, Technical Panel W-5. Workshop on Strapdown Homing Guidance Technology, DREV M-2865/87, 1987.

[3] Chabot, J.R., "Implementation of Three Monopulse Receiver Configurations and Examination of Their Performance", M. Eng. Thesis, Carleton U., Ottawa, July 1982.

[4] Charland, S., "An Investigation of the Transfer of Monopulse Tracking Between Two Coherent Point Sources", DREO TN 89-15.

[5] Morgan, K.W., private communication, 1988.

[6] van Es, H.R., TNO, The Netherlands, private communication, 1988.

APPENDIX A

CONTINUOUS TARGET ARRAY IMPLEMENTATION

An implementation of a continuous target motion array, Ref. [6], which is loosely based upon the existing design is discussed.

An array design is shown in Fig. 5. The four amplitude and phase balancing circuits feed the array switching matrix and each of the 256 possible paths from the source to the radiating elements are assumed to have identical insertion losses and electrical lengths. A balancing network ensures that the amplitude and phase at the element feed point are exactly controlled.

The proposed balancing circuit as shown in Fig. 6 varies the signal amplitude while maintaining a fixed phase. Phase is preserved by comparing the signal phase to a reference phase using a phase discriminator and adjusting a phase shifter until they are equal. The four control circuits have the same reference phase. Signal amplitude is controlled by comparing the signal level with the requested power level and adjusting the channel attenuation until these two levels are equal. Any four adjacent array elements are fed through different balancing circuits in this feed network design.

Although this design will provide precise attenuation and phase shift control, a single attenuator having low phase characteristics can be used in each of the four branches. Positioning errors will arise due to phase shifts but these errors should theoretically be within the tracking uncertainty of the TRS. In a practical array, phase will be difficult to control.

A practical first step would be to limit the arrays to a single dimension. The control is significantly simplified, as shown in Fig. 7.

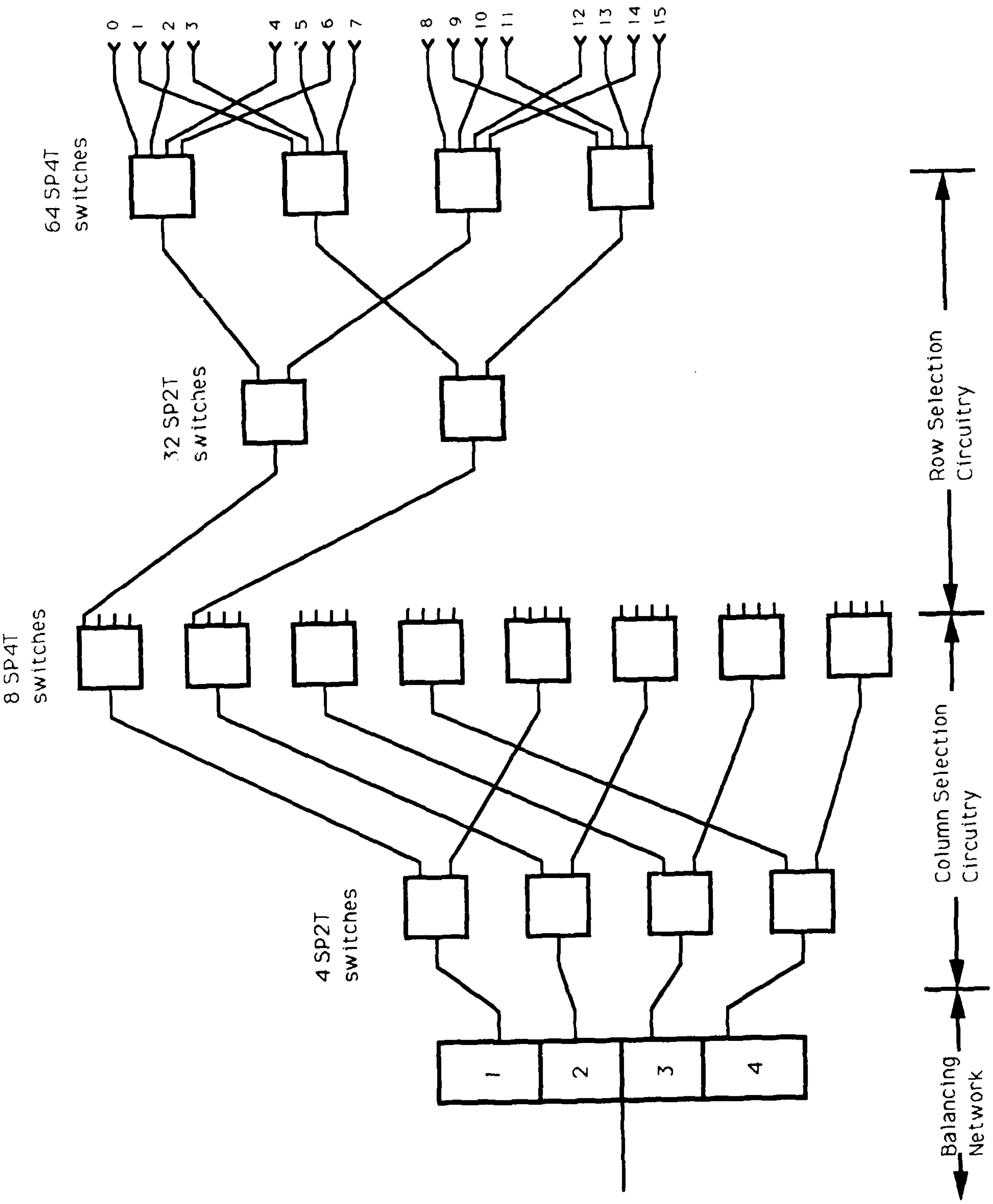

Figure 5 A Proposed Continuous Array Feed Network Design

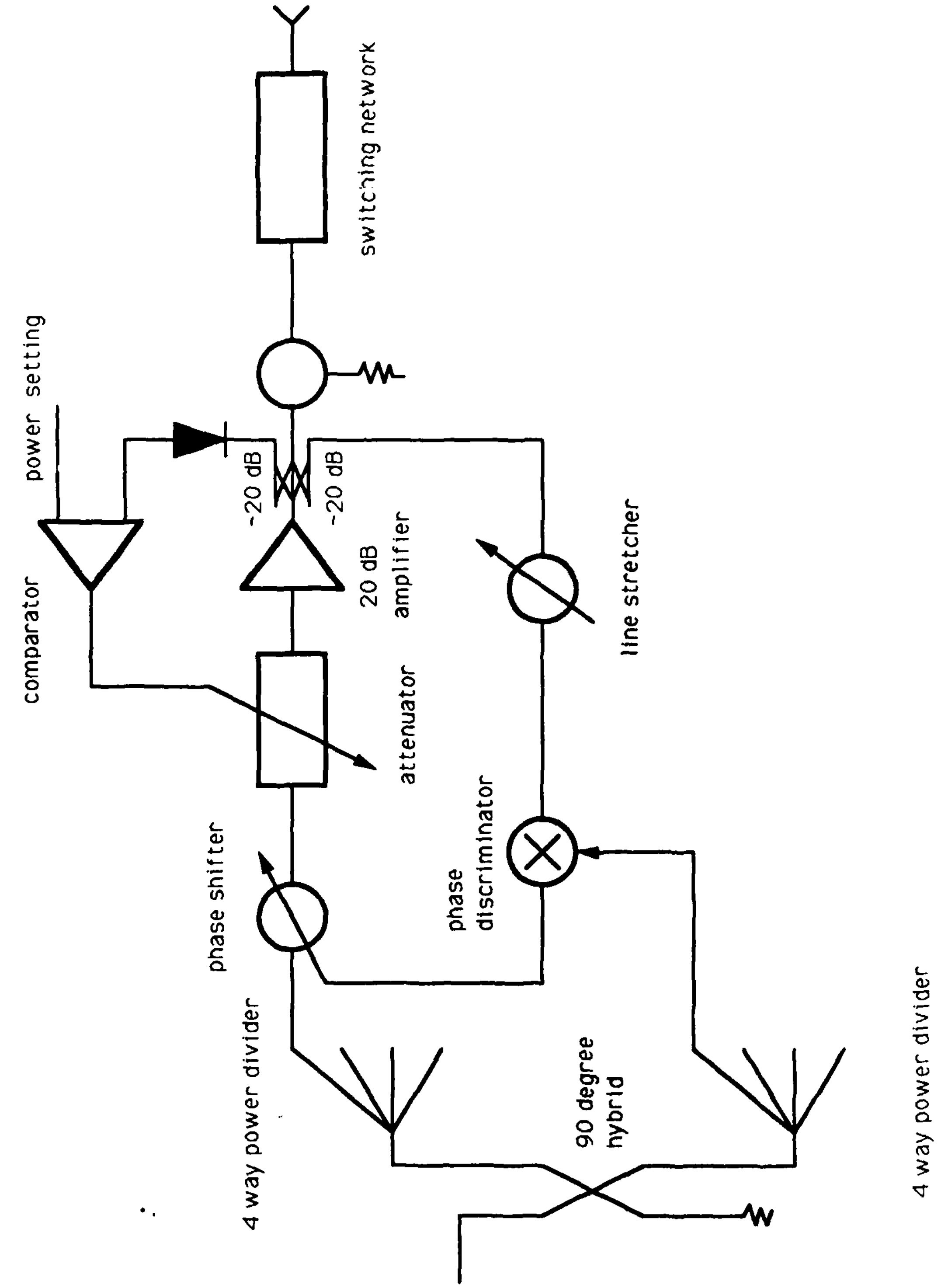

Figure 6 A Proposed Balancing Circuit Design

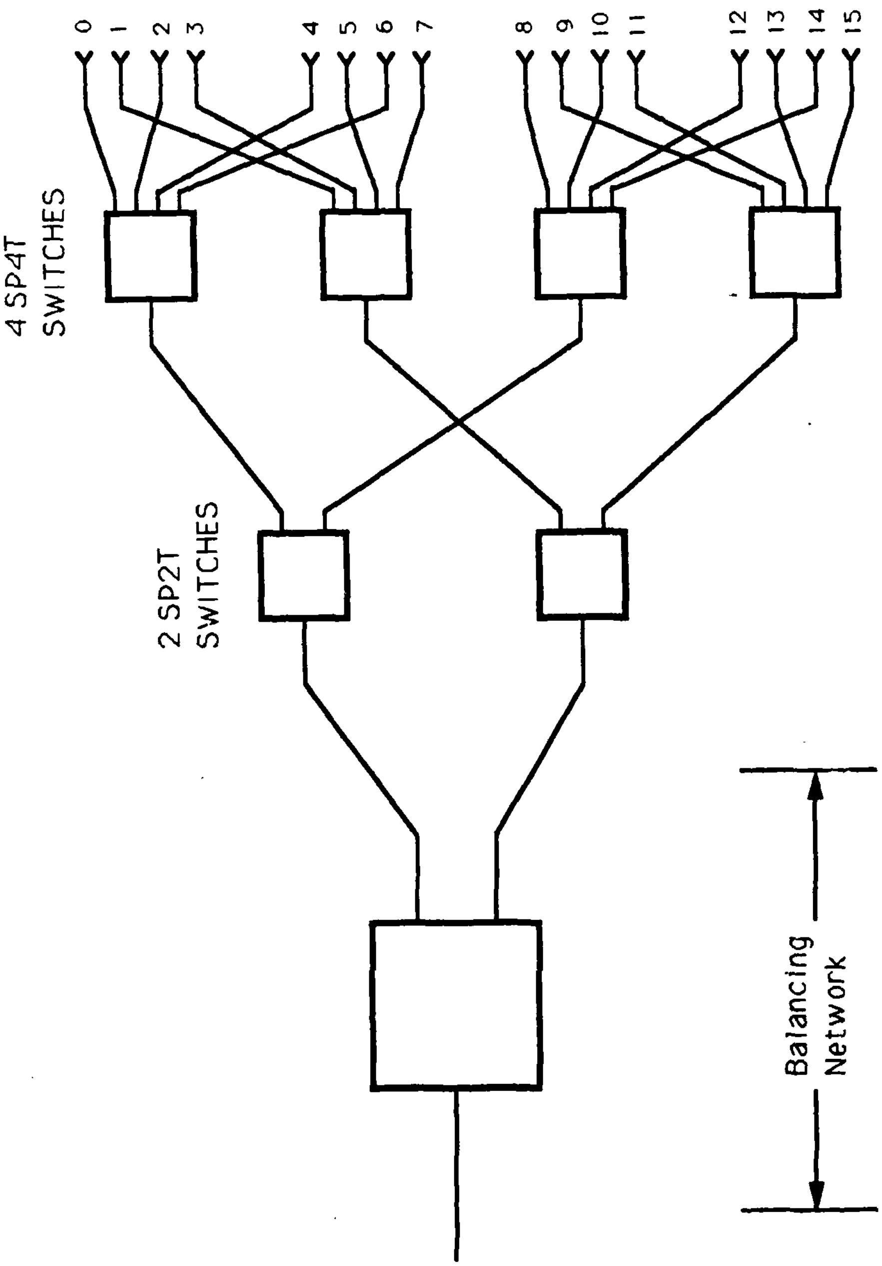

Figure 7 A Proposed Single Dimension Array Design

APPENDIX B

THREAT SIMULATION WITH POSITIONING PEDESTAL

For target motion simulation, a positioning pedestal can be used to replicate the dynamics of different threat types in an SLOS mode. The features involved in simulating these threats are considered. These simulations may all be performed in open-loop but the basic configurations for closed-loop testing are examined.

Surface-To-Air Missiles

For command guided missiles jamming is directed against the ground based target tracker. This scenario can be simulated by mounting a tracking radar on a motion pedestal and positioning the pedestal to implement all target/tracker geometry changes. Missile trajectory analysis need not be performed on-line and in real time. If the command guided missile is assumed to be perfectly tracked by the missile tracker and target tracking data as a function of time is recorded, the missile trajectory can be computed off line.

Simulation of semi-active threats depends upon whether the test countermeasure is directed against the target tracker or missile seeker.

Representation of target/tracker geometry is identical to that of the command guided missile threat case. The missile trajectory can be calculated in two ways. The missile's position can be assumed to be perfectly known while the target position is measured by the tracking radar. Missile trajectory is calculated as it would be in the command guided case. This technique indicates effectiveness in jamming a tracking radar but is not a realistic model of the overall threat system performance. Since a semi-active missile seeker tracks reflected illuminator signal energy, target tracking radar angle errors may not be sufficient to degrade the illuminator signal and affect missile performance. A more accurate technique would be to model the missile seeker, illuminator antenna patterns, illumination power levels, and received seeker power levels in software. The missile behaviour can be predicted more accurately.

All target/missile orientations can be represented by positioning a pedestal-mounted seeker. The dynamic requirements are greater for this mode of operation since the target may perform manoeuvres and the missile must respond. Hardware simulation of simultaneous tracker and seeker jamming is not practical.

Air-To-Air Missiles (Semi-Active)

The experimental configuration is similar to that of a semi-active surface to air missile with anti-seeker countermeasures. The missile trajectory can be computed from the seeker data in real time.

The target/airborne radar geometry can be implemented on the pedestal. The dynamic requirements will be less because the tracking aircraft will attempt to maintain the target within its field of view. A man-in-the-loop is required to simulate pilot behaviour during radar lock on a target. Missile trajectory is calculated by assuming flight in command guided mode based on radar data received by the tracking radar.

Surface-To-Surface Missiles

The target/missile geometry can be implemented on the motion pedestal. Missile flight profiles can be easily programmed into the scenario for open-loop simulation. The homing phase may be implemented in a closed-loop mode for ECM testing. The dynamic performance requirements of this scenario are low due to the lack of ship target manoeuvrability. A high diving terminal phase manoeuvre can be implemented at a predetermined target range. Countermeasures which are directed against the acquisition mode of the radar can be modelled in open-loop since the missile trajectory data is not critical at that stage of an engagement.

Air-To-Surface Missiles

The implementation of the homing mode of this threat is essentially the same as that for surface to surface missiles.

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(U) This note addresses the basic issues involved in modelling simulations in DREO's Electronic Warfare Engagement Simulation Facility. Fundamental design and implementation problems in DREO's attempt to model missile attacks against simulated targets are highlighted and possible solutions are presented. This note also examines some of the advantages and disadvantages of open-loop versus closed-loop hardware testing at DREO. Alternative simulation approaches using solely software models or a Modular Adaptable Radar Simulator facility are discussed.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

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ELECTRONIC WARFARE
ELECTRONIC WARFARE SIMULATION
HARDWARE-IN-THE-LOOP SIMULATION
MISSILE GUIDANCE
SIMULATORS
THREAT RADAR SIMULATOR